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Multi-Criteria Supplier Selection Based on Fuzzy Pairwise Comparison in AHP

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Abstract

Supplier selection process has become an important force that influences the management of industrial relations. Therefore, it has a great importance for companies. Supplier selection process is a complex multi criteria decision making process where problems include multiple objects. In this study, multi criteria decision making problems, decision makers' opinions on these problems, and the solution processes are discussed. The proposed algorithm, modeled with trapezoidal fuzzy numbers, is applied to an example in the literature. The results obtained from the proposed algorithm and from the existing method are compared in terms of the quality of the solution.

1. INTRODUCTION

Supplier selection, which is the first step in the supply chain, has a crucial role in helping businesses reach their goals and objectives, maintain their competitiveness and gain greater share in the market. Recent studies indicate that in the supplier selection process, considering the low-cost measure criterion alone is not enough, but also the criteria such as quality, delivery time and performance must be taken into account in the evaluation process. In this context, the supplier selection is a multi-criteria decision making (MCDM) method problem that involves a large number of quantitative and qualitative factors in a hierarchical structure within the company structure. MCDM method is one of the appropriate optimization techniques to overcome the complex decision-making problems and it is used in cases with multiple objectives. For a MCDM problem which has more than one target, the targets can be conflicting. Therefore, achieving the best value for all targets at the same time is not always possible. In these cases, the objective functions are weighted using the AHP method. In the classic AHP method, importance weight of each criterion is determined using crisp numbers, whereas in the fuzzy AHP method, criteria comparison is done by using fuzzy numbers and linguistic variables.

There are many studies on fuzzy based Analytic Hierarchy Process (Fuzzy AHP) in the literature [1-6]. Chang defined a new approach for handling fuzzy AHP, with the use of triangular fuzzy numbers for pairwise comparison scale of fuzzy AHP [7]. Budak and Ustundag developed a decision-making model for selection of the appropriate Real Time Location Systems (RTLS) technology for companies operating in different sectors. They determined three main criteria by existing literature and with the help of the experts, namely economic, technical and implementation factors and proposed Fuzzy AHP method to select the appropriate RTLS technology [8]. Chou et al. developed a fuzzy AHP method for tackling the uncertainty and imprecision existing in multi criteria decision process. They used fuzzy pair-wise comparison judgments in place of exact numerical values of the comparison ratios in their proposed method [9]. Ghassemi and Danesh proposed an integrated two-step model was developed based on the fuzzy AHP and TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) methods in

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their article [10]. Shaw et al. presented an integrated approach for selecting the appropriate supplier in the supply chain, addressing the carbon emission issue, using fuzzy AHP and fuzzy multi-objective linear programming [11]. Cakir and Canbolat proposed an inventory classification system based on the fuzzy AHP, a commonly used tool for MCDM problems [12]. Ashtiani and Azgomi formulated trust as a MCDM problem and used fuzzy AHP in their paper [13]. Junior et al. presented a comparative analysis of fuzzy AHP and fuzzy TOPSIS methods in the context of supplier selection decision making [14]. Lee et al. employed fuzzy AHP and fuzzy TOPSIS in their paper [15]. Ren and Lutzen aimed at developing the methodology for technology selection for emissions reduction from shipping by combining fuzzy AHP and VIKOR (Vise Kriterijumska Optimizacija I Kompromisno Resenje) in their study [16]. Yadav and Sharma proposed a multi-criteria supplier selection model using fuzzy AHP approach for a leading automobile company in India [17]. The aim of Hicdurmaz's study is to propose a fuzzy MCDM approach to Software Life Cycle Model (SLCM) selection, since fuzzy sets are inevitable in representing uncertainty, vagueness and human subjectivity. This study provides a view of existing software life cycle models, important factors to be considered and a new approach for SLCM selection [18]. Calabrese et al. proposed a model for intellectual capital evaluation by integrating fuzzy logic and AHP [19]. Yucel and Guneri expressed the linguistic values as trapezoidal fuzzy numbers to assess the weights of the factors. They obtained the weights by calculated the distances of each factor between Fuzzy Positive Ideal Rating and Fuzzy Negative Ideal Rating [20]. Yazdani is focused on finding the right supplier based on fuzzy MCDM process. He used AHP and TOPSIS in his study [21]. Zhu et al. proved the basic theory of the triangular fuzzy number in their paper [22]. Zheng et al. utilized trapezoidal fuzzy numbers to determine the weights of the indexes and evaluate the performance of the indexes. The purpose of their paper is to develop a methodology for the work safety evaluation and early warning rating system [23]. In the method proposed by Zhang et al., the experts' opinions are described by trapezoidal fuzzy numbers, and the fuzzy Delphi method is adopted to adjust each expert's opinion to achieve the consensus condition [24]. Chen et al. defended that their article the proposed model is very well suited as a decision- making tool for supplier selection decisions. And they used TOPSIS method [25]. Azadnia et al. proposed an integrated approach of rule-based weighted fuzzy method, fuzzy analytical hierarchy process and MCDM for sustainable supplier selection and order allocation combined with multi-period multi-product lot-sizing problem. [26]. Jaiswal et al. presented an efficient multi-criteria decision support model (MCDSM) to prioritize susceptible areas in a watershed for soil conservation measures based on impact analysis of topography, climate, morphology, soil, land cover, management and conservation factors [27]. The aim of Jakhar's study is to propose help decision makers, managers, and practitioners to achieve economic growth, societal development, and environmental protection by developing sustainable supply chain performance measures and proposes a partner selection and flow allocation decision-making model [28]. Kannan et al. presented an integrated approach, of fuzzy multi attribute utility theory and multi-objective programming, for rating and selecting the best green suppliers according to economic and environmental criteria and then allocating the optimum order quantities among them [29]. Akbas and Dalkilic handled MCDM problems and decision makers' opinions for these problems. At first, they solved fuzzy linear programming problems by Zimmerman approach. Then, they weighted triangular and trapezoidal fuzzy numbers as two different formats, solved the problems with Hybrid approach [30]. Efe et al. aimed to establish an occupational health and safety policy for three firms. They provided to overcome the drawbacks of traditional Failure Mode and Effects Analysis by using an integrated intuitionistic fuzzy multi-criteria decision making method and a linear programming. They used fuzzy AHP and fuzzy VIKOR method in their work [31]. Buyukozkan and Gocer proposed a new integrated methodology in their article. The focus of their study is intuitionistic fuzzy (IF) MCDM methods which have attracted much attention from researchers in recent years [32]. Hamdan and Cheaitou proposed decision-making tool to solve a multi-period green supplier selection and order allocation problem. They used fuzzy TOPSIS and AHP method in their paper [33]. Secundo et al. proposed a fuzzy extended analytic hierarchy process (FEAHP) approach for service supplier evaluation [34]. Baran and Erol proposed a mathematical model to obtain products more quickly and determine how much you need to order from the supplier. They used AHP method in their article [35]. In their work, Wang et al. showed by examples that the priority vectors determined by the extent analysis method proposed by Chang do not represent the relative importance of decision criteria or alternatives [36]. Zhu et al. claimed that the extent analysis method proposed by Chang contains some mistakes and proposed a different method [37].

The organization of the paper is as follows: In Section 2, basic definitions related fuzzy multi-objective linear programming are given. In Section 3, in order to handle the problem that multi objectives have different weights which are uncertain, fuzzy AHP method is introduced. In Section 4, an algorithm which uses trapezoidal fuzzy numbers to weight the objective functions is briefly mentioned. In Section 5, the proposed algorithm is applied to an example in the literature and the results, existing in the literature and obtained with the proposed algorithm, were compared.

2. BASIC DEFINITIONS RELATED FUZZY MULTI-OBJECTIVE LINEAR PROGRAMMING

Definition 2.1. The model relative to the solution of MCDM problems is established to determine the best objective value that satisfies the decision maker in the appropriate solution space. The general mathematical structure of MCDM models is,

$$P_1 \begin{cases} maxz_1 = c\underline{x} = f_1(x) \\ maxz_2 = c\underline{x} = f_2(x) \\ \vdots \\ maxz_J = c\underline{x} = f_J(x) \\ g_i(x) \leq 0 \quad (i = 1 \dots m) \\ \underline{x} \geq 0 \end{cases} \tag{1}$$

where,

$f_J(x)$: J. objective function,
$g_i(x)$: i. constraint function,
J : The number of objective functions,
m : The number of restrictive conditions,
$\underline{x}$: The decision variables vector.

Definition 2.2. In analytic hierarchy process (AHP), the relative importance of each criterion determines by the decision makers. Then, alternatives are selected based on each criterion. The first step in forming a hierarchical structure in AHP is to determine the criteria and the sub-criteria that belong to the decision maker's objectives. In AHP, firstly, objectives are determined and the criteria affecting the selection are determined in line with these objectives. Then, potential alternatives are determined by considering the criteria. Finally, a hierarchical structure is formed for the decision. After determining all the factors that make up the hierarchy, pairwise comparison decision matrices are established to determine the importance levels of each criterion. Generally, these matrices are created using the 1-9 importance scale suggested by Saaty [38].

Definition 2.3. Classical linear programming problem proposed to find the minimum or maximum values of a linear function under some constraints. For some situations, the constraints or objective function like available labor hours and materials may not be specified in precise. In such situations, using some type of fuzzy linear programming is more feasible than using classical linear programming. In linear programming problems, the fuzzy state can occur in different ways depending on the fuzziness of the parameters. The fuzziness state in this study is shown by the fuzzy linear model in Eq. (2).

$$\begin{aligned} &maximize && \underline{\tilde{c}}x \\ &subject\ to && \underline{A}x \lesssim \underline{b} \\ & && x \geq 0 \end{aligned} \tag{2}$$

Where the fuzzy inequality $\lesssim$ is characterized by membership functions. In the literature, there are many membership functions. These functions vary according to the structure of discussed problem. The most common are triangular and trapezoidal membership functions.

Definition 2.4. A trapezoidal fuzzy number $\tilde{a}$ can be defined as $(a^1,\ a^2,\ a^3,\ a^4)$, shown in Figure 1. The membership function, $\mu_{\tilde{n}}(x)$ is defined as [39].

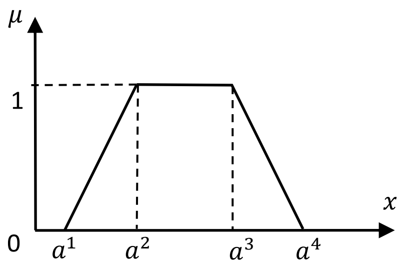

Figure. 1. *General form of a trapezoidal fuzzy number*

$$\mu_{\tilde{n}}(x)=\begin{cases}\dfrac{x-a^1}{a^2-a^1}, & a^1<x<a^2\\ 1, & a^2\le x\le a^3\\ \dfrac{a^4-x}{a^4-a^3}, & a^3<x<a^4\\ 0, & x\le a^1 \text{ and } x\ge a^4\end{cases} \tag{3}$$

Definition 2.5. For a trapezoidal fuzzy number $\tilde{a}=(a^1,\ a^2,\ a^3,\ a^4)$, if $a^2=a^3$, then $\tilde{a}$ is called a triangular fuzzy number. By the extension principle, the fuzzy sum $\oplus$ and fuzzy subtraction $\ominus$ of any two trapezoidal fuzzy numbers; but the multiplication $\otimes$ of any two trapezoidal fuzzy numbers is only an approximate trapezoidal fuzzy number [40]. Given any two positive trapezoidal fuzzy numbers, $\tilde{a}=(a^1,\ a^2,\ a^3,\ a^4)$, $\tilde{b}=(b^1,\ b^2,\ b^3,\ b^4)$, and a positive crisp number r, some main operations of fuzzy numbers $\tilde{a}$ and $\tilde{b}$ can be expressed as follows:

$$\begin{aligned}&\tilde{a}\ \oplus\ \tilde{b}=(a^1+b^1,\ a^2+b^2,\ a^3+b^3,\ a^4+b^4),\\&\tilde{a}\ \ominus\ \tilde{b}=(a^1-b^4,\ a^2-b^3,\ a^3-b^2,\ a^4-b^1),\\&\tilde{a}\ \otimes\ \tilde{b}\cong(a^1\times b^1,\ a^2\times b^2,\ a^3\times b^3,\ a^4\times b^4),\\&\tilde{a}\ \otimes\ r=(a^1\times r,\ a^2\times r,\ a^3\times r,\ a^4\times \mathrm{r}).\end{aligned} \tag{4}$$

Definition 2.6. Although AHP’s aim is to reveal the knowledge of decision makers, conventional AHP still do not reflect the human thought accurately. The AHP method uses exact numbers in the pairwise comparison process. On real world problems, instead of using exact numbers that represent the decision makers’ opinions, linguistic assessment is more realistic and appropriate. The fuzzy AHP method has been developed to get rid of these problems. In the fuzzy AHP method, fuzzy numbers are used to relieve decision makers. In fuzzy AHP method, priorities and weights of factors are determined by comparing the factors using the fuzzy numbers.

3. AN ALGORITHM FOR MULTI-CRITERIA SUPPLIER SELECTION BASED ON FUZZY PAIRWISE COMPARISONS

The steps of algorithm for weighting of objective functions by using trapezoidal fuzzy numbers are expressed as follow:

Step 1: The maximum and minimum values for each objective function as to the application are calculated based on the constraints of the model.

Step 2: The membership values of the fuzzy objective functions are determined in cases where the objective function is both minimum and maximum. If the objective is minimization, the membership function is as follows:

$$\mu_{Zj}(x)=\begin{cases}1, & Z_j(x)\le Z_j^{min}\\ \dfrac{[Z_j^{max}-Z_j(x)]}{[Z_j^{max}-Z_j^{min}]}, & Z_j^{min}\le Z_j(x)\le Z_j^{max}\\ 0, & Z_j(x)\ge Z_j^{max}\end{cases} \tag{5}$$

If the objective function is maximization, the membership function is as follows:

$$\mu_{Zj}(x) = \begin{cases} 1 & , \quad Z_j(x) \le Z_j^{min} \\ \dfrac{[Z_j(x) - Z_j^{min}]}{[Z_j^{max} - Z_j^{min}]}, & Z_j^{min} \le Z_j(x) \le Z_j^{max} \\ 0 & , \quad Z_j(x) \ge Z_j^{max} \end{cases} \tag{6}$$

The linear membership function for the fuzzy constraints is given by Eq. (7):

$$\mu_{g_t}(x) = \begin{cases} 1 & , \quad g_t(x) \le b_t \\ \left[1 - \dfrac{\{g_t(x) - b_t\}}{d_t}\right], & b_t \le g_t(x) \le b_t + d_t \\ 0 & , \quad b_t + d_t \le g_t(x) \end{cases} \tag{7}$$

for all fuzzy parameters $t = 1, \ldots T$. The interpretation of d_t is the tolerance value.

Step 3: The comparison matrix of each criterion with each other (Table 2) is calculated by considering the centers of the fuzzy importance weights (b_{LP}) determined by experts (Table 1). The importance weights of the criteria with respect to each other are obtained by the proportion of the importance weights of each criterion according to the other criteria.

Table 1. *Importance weights of criteria from decision makers*

Criteria	D_1	D_2	$\cdots$	D_P
C_1	b_{11}	b_{12}	$\cdots$	b_{1P}
C_2	b_{21}	b_{22}	$\cdots$	b_{2P}
$\vdots$	$\vdots$	$\vdots$	$\cdots$	$\vdots$
C_L	b_{L1}	b_{L2}	$\cdots$	b_{LP}

Step 4: Importance weights obtained from Step 3 are converted to trapezoid fuzzy numbers to form a comparison matrix of the criteria. The comparison values for each criterion (a_{ijk}) given by the decision makers are determined (L: number of criteria; P: number of decision makers; $i: 1, \ldots, L$; $j: 1, \ldots, L$; $k: 1, \ldots, P$).

Table 2*. General form of the comparison matrix of each criterion with each other*

	C_1	C_2	$\cdots$	C_L
C_1	(1,1,1,1) $\vdots$ (1,1,1,1)	a_{121} $\vdots$ a_{12P}	$\cdots$	a_{1L1} $\vdots$ a_{1LP}
C_2	a_{211} $\vdots$ a_{21P}	(1,1,1,1) $\vdots$ (1,1,1,1)	$\cdots$	a_{2L1} $\vdots$ a_{2LP}
$\vdots$	$\vdots$	$\vdots$	(1,1,1,1) $\vdots$ (1,1,1,1)	$\vdots$
C_L	a_{L11} $\vdots$ a_{L1P}	a_{L21} $\vdots$ a_{L2P}	$\cdots$	(1,1,1,1) $\vdots$ (1,1,1,1)

Step 5: The geometric mean of decision maker's opinions consisting of trapezoidal fuzzy numbers is taken, and new trapezoidal numbers (A_{ij}) are obtained for paired comparison of each criterion.

$$a_{ij}^{n} = \left(a_{ij1}^{n} * a_{ij2}^{n} * \ldots * a_{LLP}^{n}\right)^{\frac{1}{P}},\ (n = 1,2,3,4) \text{ and} \tag{8}$$

$$A_{ij} = [a_{ij}^{1} \quad a_{ij}^{2} \quad a_{ij}^{3} \quad a_{ij}^{4}]. \tag{9}$$

Step 6: M_{ij} is obtained by sum of all new generated trapezoidal fuzzy numbers.

$$M_{ij} = \sum_{i=1}^{n}\sum_{j=1}^{n} A_{ij} \tag{10}$$

Step 7: The membership value for each criterion is calculated using $F_i = \sum_{j=1}^{n} A_{ij} \otimes \left[M_{ij}\right]^{-1}$ formula.

Step 8: Each membership values obtained in Step 5 ($F_i\ [f_i^1\ f_i^2\ f_i^3\ f_i^4]$) are compared with each other. When $f_1^1 \geq f_2^1,\ f_1^2 \geq f_2^2,\ f_1^3 \geq f_2^3,\ f_1^4 \geq f_2^4$, the trapezoidal fuzzy number $F_1\ [f_1^1\ f_1^2\ f_1^3\ f_1^4]$ is greater than the trapezoidal fuzzy number $F_2\ [f_2^1\ f_2^2\ f_2^3\ f_2^4]$, and the value of membership (μ_d) is expressed as $V(F_1 \geq F_2) = \mu_d = 1$. When $f_1^1 \geq f_2^4$, the value of membership (μ_d) is expressed as $V(F_1 \geq F_2) = 0$. In other cases, the value of membership (μ_d) is expressed as;

$$V(F_2 \geq F_1) = \mu_d = \frac{f_1^1 - f_2^4}{(f_2^3 - f_2^4) - (f_1^2 - f_1^1)} \tag{11}$$

Step 9: As a result of the comparison, the minimum membership values are determined, and the weight vector is obtained.

$$d(F_L) = Min\{V(F_l \geq F_1), \ldots, V(F_L \geq F_{L-1})\}$$
$$W' = (w_1, w_2, \ldots, w_L)^T,\ w_l = d(F_l). \tag{12}$$

Step 10: By utilizing w_l obtained by trapezoidal fuzzy numbers, corresponding to opinion of decision makers, the linear programming problem given by Eq. (13) is modeled.

$$\begin{aligned}
&Max \sum_{l=1}^{L} w_l\lambda_l + \sum_{t=1}^{T} \beta_t\gamma_t \\
&\lambda_l \leq \mu_{Z_l}(x), \quad l = 1, \ldots, L, \text{(for all objective functions)}, \\
&\gamma_t \leq \mu_{g_t}(x), \quad t = 1, \ldots, T, \text{(for fuzzy constraints)}, \\
&\sum_{l=1}^{L} w_l + \sum_{t=1}^{T} \beta_t = 1 \\
&g_k(x) \leq b_k, \quad k = 1,2, \ldots, K, \text{(for deterministic constraints)}, \\
&\lambda_l, \gamma_t \in [0,1],\ w_l, \beta_t \geq 0,\ x_m \geq 0, (m = 1, \ldots, M).
\end{aligned} \tag{13}$$

In Eq. (13), w_l, β_t are the weights coefficients that present the relative importance among the fuzzy goals and fuzzy constraints. λ_l and γ_t represents the constraint and the fuzzy constraint parameters.

4. APPLICATION

The proposed algorithm in this study is applied to an example in the literature and the results, existing in the literature and obtained with the proposed algorithm, were compared. In the Yucel and Guneri's paper, a committee of decision makers, D_1, D_2 and D_3, has been constituted for the supplier selection and then committee selected net price, quality and on-time delivery as selection criteria and demand as fuzzy constraint [20].

Table 3. *Suppliers' quantitative information*

Supplier	Net price	Quality (%)	Delivery (%)	Capacity
A_1	5	80	90	400
A_2	7	90	80	450
A_3	4	85	85	450

The net price, quality, on-time delivery values and capacity constraints of each candidate supplier, A_1, A_2 and A_3, are presented in Table 3. In selection problem, demand is treated as a fuzzy number and predicted to be about 800.

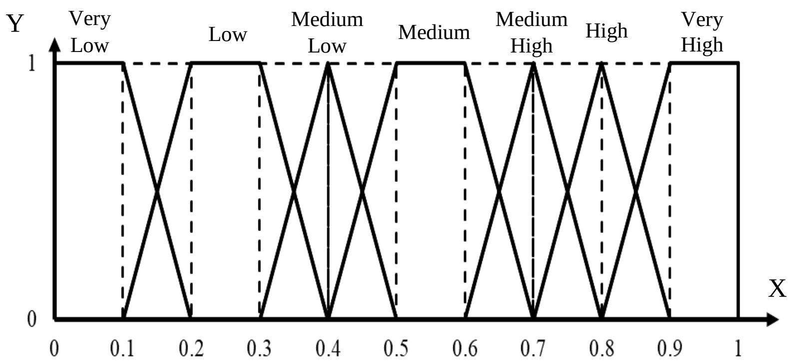

Figure. 2. *Linguistic variables for importance weight*

Three decision makers used the linguistic variables shown in Figure 2 to assess the importance of criteria and demand constraint. The linguistic values determined by decision makers are shown in Table 4.

Table 4. *Importance weights of criteria and constraint from three decision makers*

Criteria and constraint	D_1	D_2	D_3
Net price	VH	VH	H
Quality	H	H	H
Delivery	H	MH	H
Demand	H	MH	MH

The multi-objective linear formulation of numerical example is given as P_1.

P_1: $Z_{1(min)} = 5x_1 + 7x_2 + 4x_3,$

$$Z_{2(max)} = 0.80x_1 + 0.90x_2 + 0.85x_3,$$

$$Z_{3(max)} = 0.90x_1 + 0.80x_2 + 0.85x_3,$$

$$x_1 + x_2 + x_3 = 800,$$

$$x_1 \leq 400,\ x_2 \leq 450,\ x_3 \leq 450,\ x_i \geq 0, \qquad i = 1,2,3.$$

Three objective functions Z_1, Z_2 and Z_3 are respectively net price, quality and on-time delivery goals, x_i is the number of units purchased from i th supplier.

Table 5. *The maximum and minimum values of the objective functions*

Objective function	$\mu = 0$	$\mu = 1$	$(\mu = 0) - (\mu = 1)$
Z_1	4900	3550	1350
Z_2	702.5	660	42.5
Z_3	700	657.5	42.5

Upper and lower bounds in Table 5 are used to construct membership functions expressed as:

$$\mu_{Z_1}(x) = \begin{cases} 1 & Z_1 \leq 3550, \\ \frac{4900 - Z_1}{1350} & 3550 < Z_1 < 4900, \\ 0 & Z_1 \geq 4900. \end{cases}$$

$$\mu_{Z_2}(x) = \begin{cases} 1 & Z_2 \geq 702.5, \\ \frac{Z_2 - 660}{42.5} & 660 < Z_2 < 702.5, \\ 0 & Z_2 \leq 660. \end{cases}$$

$$\mu_{Z_3}(x) = \begin{cases} 1 & Z_3 \geq 700, \\ \frac{Z_3 - 657.5}{42.5} & 657.5 < Z_3 < 700, \\ 0 & Z_3 \leq 657.5. \end{cases}$$

$$\mu_{gd}(x) = \begin{cases} \frac{d(x) - 750}{50} & 750 < d(x) < 800, \\ \frac{875 - d(x)}{75} & 800 \leq d(x) < 875, \\ 0 & d(x) \leq 750, d(x) \geq 875. \end{cases}$$

The fuzzy comparison values obtained by using the importance weights that decision makers gave to each criterion are shown in Table 6.

Table 6. *Importance weights given by three decision makers*

		Net price	Quality	Delivery	Demand
Net price	**DM1**	(1, 1, 1, 1)	(0.65, 0.95, 1.55, 1.85)	(0.65, 0.95, 1.55, 1.85)	(0.65, 0.95, 1.55, 1.85)
	DM2	(1, 1, 1, 1)	(0.65, 0.95, 1.55, 1.85)	(0.82, 1.12, 1.72, 2.02)	(0.82, 1.12, 1.72, 2.02)
	DM3	(1, 1, 1, 1)	(1,1,1,1)	(1,1,1,1)	(0.54, 0.84, 1.44, 1.74)
Quality	**DM1**	(0.54, 0.65, 1.05, 1.54)	(1, 1, 1, 1)	(1, 1, 1, 1)	(1, 1, 1, 1)
	DM2	(0.54, 0.65, 1.05, 1.54)	(1, 1, 1, 1)	(0.54, 0.84, 1.44, 1.74)	(0.54, 0.84, 1.44, 1.74)
	DM3	(1, 1, 1, 1)	(1, 1, 1, 1)	(1, 1, 1, 1)	(0.54, 0.84, 1.44, 1.74)
Delivery	**DM1**	(0.54, 0.65, 1.05, 1.54)	(1, 1, 1, 1)	(1, 1, 1, 1)	(1, 1, 1, 1)
	DM2	(0.50, 0.58, 0.89, 1.22)	(0.57, 0.69, 1.19, 1.85)	(1, 1, 1, 1)	(1, 1, 1, 1)
	DM3	(1, 1, 1, 1)	(1, 1, 1, 1)	(1, 1, 1, 1)	(0.54, 0.84, 1.44, 1.74)
Demand	**DM1**	(0.54, 0.65, 1.05, 1.54)	(1, 1, 1, 1)	(1, 1, 1, 1)	(1, 1, 1, 1)
	DM2	(0.50, 0.58, 0.89, 1.22)	(0.57, 0.69, 1.19, 1.85)	(1, 1, 1, 1)	(1, 1, 1, 1)
	DM3	(0.57, 0.69, 1.19, 1.85)	(0.57, 0.69, 1.19, 1.85)	(0.57, 0.69, 1.19, 1.85)	(1, 1, 1, 1)

Table 7 is obtained by taking the geometric mean of decision maker opinions.

Table 7. *Fuzzy pair wise comparisons among criteria*

	Net price	Quality	Delivery	Demand
Net price	(1, 1, 1, 1)	(0.75, 0.97, 1.34, 1.51)	(0.81, 1.02, 1.39, 1.55)	(0.66, 0.96, 1.57, 1.87)
Quality	(0.66, 0.75, 1.03, 1.33)	(1, 1, 1, 1)	(0.81, 0.94, 1.13, 1.20)	(0.66, 0.89, 1.28, 1.45)
Delivery	(0.64, 0.72, 0.98, 1.23)	(0.83, 0.89, 1.06, 1.23)	(1, 1, 1, 1)	(0.81, 0.94, 1.13, 1.20)
Demand	(0.54, 0.64, 1.04, 1.51)	(0.69, 0.78, 1.12, 1.51)	(0.83, 0.89, 1.06, 1.23)	(1, 1, 1, 1)

By the implementation of the proposed algorithm weights can be obtained as follows,

$M_{mn} = \sum_{m=1}^{4}\sum_{n=1}^{4} A_{mn} = (12.71, 14.39, 18.12, 20.82)$

$[M_{mn}]^{-1} = (0.048, 0.055, 0.069, 0.07)$

The values of membership degree for each criterion is calculated as below;

$\sum_{m=1}^{4} A_{1m} = (3.22, 3.95, 5.29, 5.93)$

$\sum_{m=1}^{4} A_{2m} = (3.14, 3.58, 4.44, 4.98)$

$\sum_{m=1}^{4} A_{3m} = (3.29, 3.55, 4.17, 4.66)$

$\sum_{m=1}^{4} A_{4m} = (3.06, 3.31, 4.22, 5.25)$

$F_1 = \sum_{m=1}^{4} A_{1m} \otimes [M_{mn}]^{-1} \cong (0.15, 0.22, 0.37, 0.47)$

$F_2 = \sum_{m=1}^{4} A_{2m} \otimes [M_{mn}]^{-1} \cong (0.15, 0.20, 0.31, 0.39)$

$F_3 = \sum_{m=1}^{4} A_{3m} \otimes [M_{mn}]^{-1} \cong (0.16, 0.20, 0.29, 0.37)$

$F_4 = \sum_{m=1}^{4} A_{4m} \otimes [M_{mn}]^{-1} \cong (0.15, 0.18, 0.29, 0.41)$

The weights of criteria are obtained by using comparison method for trapezoidal fuzzy numbers;

$V(F_1 \geq F_2) = 1, V(F_1 \geq F_3) = 0.706, V(F_1 \geq F_4) = 1$

$V(F_2 \geq F_1) = 0.347, V(F_2 \geq F_3) = 0.550, V(F_2 \geq F_4) = 0.568$

$V(F_3 \geq F_1) = 0.294, V(F_3 \geq F_2) = 0.450, V(F_3 \geq F_4) = 0.524$

$V(F_4 \geq F_1) = 0.289, V(F_4 \geq F_2) = 0.432, V(F_4 \geq F_3) = 0.476$

$d(F_1) = Min\, V(F_1 \geq F_2, F_3, F_4) = 0.706$

$d(F_2) = Min\, V(F_2 \geq F_1, F_3, F_4) = 0.347$

$d(F_3) = Min\, V(F_3 \geq F_1, F_2, F_4) = 0.294$

$d(F_4) = Min\, V(F_4 \geq F_1, F_2, F_3) = 0.289$

$$W' = \left(d(F_1), d(F_2), d(F_3), d(F_4)\right)^T$$
$$= (0.4312, 0.2122, 0.1799, 0.1767)$$

The structure of the new fuzzy multi-objective linear model created using the final weights obtained from the proposed algorithm is given as P_2.

P_2: $max \;\; 0.4312\lambda_1 + 0.2122\lambda_2 + 0.1799\lambda_3 + 0.1767\gamma_1$

$$\lambda_1 \leq \frac{4900-(5x_1+7x_2+4x_3)}{1350},$$

$$\lambda_2 \leq \frac{(0.80x_1+0.90x_2+0.85x_3)-660}{42.5},$$

$$\lambda_3 \leq \frac{(0.90x_1+0.80x_2+0.85x_3)-657.5}{42.5},$$

$$\gamma_1 \leq \frac{875-(x_1+x_2+x_3)}{75},$$

$$\gamma_1 \leq \frac{(x_1+x_2+x_3)-750}{50},$$

$x_1 \leq 400,$

$x_2 \leq 450,$

$x_3 \leq 450,$

$\lambda_{j=1,2,3}, \quad \gamma_1 \in [0,1], \quad x_1, x_2, x_3 \geq 0.$

WinQSB is used to solve the problem. The optimal solution for the model is obtained as follows:

$\lambda_1 = 0.815,\ \lambda_2 = 1.00,\ \lambda_3 = 1.00,\ \gamma_1 = 0.333$
$x_1 = 400,\ x_2 = 0,\ x_3 = 450,$
$Z_1 = 3800,\ Z_2 = 702.5,\ Z_3 = 742.5$

5. DISCUSSION

The results obtained from the proposed algorithm and from the existing method in the literature are given comparatively in Table 6. As can be clearly seen from Table 6, 4075 is the result that is obtained from the solution of the first objection function (net price), which is required to be minimized, by using the existing method in the literature, 3800 is the result that is obtained from the same function's solution by using the proposed method; 702.5 is the result that is obtained from the solution of the second objection function (quality), which is required to be maximum, by using the existing method in the literature, 702.5 is the result that is obtained from the same function's solution by using the proposed method; 700 is the result that is obtained from the solution of the third objection function (on-time deliver), which is required to be maximum, by using the existing method in the literature, 742.5 is the result that is obtained from the same function's solution by using the proposed method.

As a result, it is seen that the values obtained from the proposed algorithm are better than the values obtained from the solution of the existing method in the literature.

Table 8. *The solutions obtained from the application of different methods*

The results of the proposed algorithm	The results existing in the literature
$x_1 = 400$	$x_1 = 175$
$x_2 = 0$	$x_2 = 200$
$x_3 = 450$	$x_3 = 450$
$\boldsymbol{Z_{1(min)} = 3800}$	$\boldsymbol{Z_{1(min)} = 4075}$
$Z_{2(max)} = 702.5$	$Z_{2(max)} = 702.5$
$\boldsymbol{Z_{3(max)} = 742.5}$	$\boldsymbol{Z_{3(max)} = 700}$

In the later study, the resolution process can be examined after defining unsymmetrical trapezoidal fuzzy numbers. The proposed algorithm can be extended using more objective function, constraint function and decision variables to solution of multi-criteria decision problems like portfolio selection problems.

CONFLICTS OF INTEREST

No conflict of interest was declared by the authors.

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